Experimental Techniques for SEE Tests at Low Temperatures

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Abstract-Two methods for testing microelectronic devices at low temperatures are presented in this paper. Both methods lend themselves for use in the target chamber of an accelerator. The first method utilizes a closed system that employs the Joule-Thompson effect to cool the DUT down to cryogenic temperatures. The second method uses an open system that makes use of a simple heat exchanger design to transport heat via a liquid nitrogen (LN2) line. The resolution of either method is 1 degree Celsius from room temperature down to 77°K.

I. Introduction

Temperature affects various parameters in semiconductors and dielectrics. Some of these parameters are conductivity, electron and hole mobilities, and the semiconductor's Fermi energy level to mention but a few. Microelectronic devices on board a spacecraft are routinely exposed to low temperatures during the mission lifetime. Yet, the role of temperature on single-event effects (SEE) is currently unknown. The experimental techniques discussed in this paper offer researchers the ability to explore single-event effects as a function of temperature.

II. Background

Cryogenic temperatures can be obtained by various techniques. One method uses capillary action to transport thermal energy from a heat source to a heat sink via the Joule-Thompson effect. An example of such a system is a heat pipe. Figure 1 shows the essential components of a heat pipe.

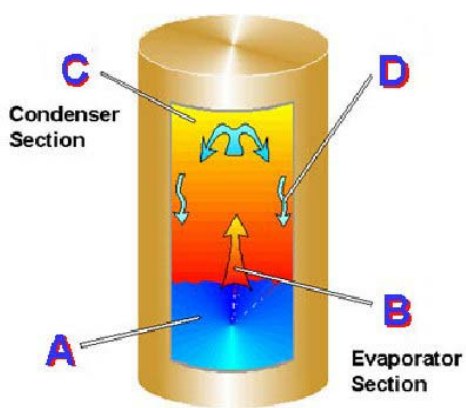

Figure 1: Schematic of a simple heat pipe.

The working fluid in the heat pipe circulates in a closed system as depicted in figure 1. The circulating cycle begins with the fluid in the liquid phase, shown as A. Next, the fluid is absorbed by a wick or forced through a network of capillary size vessels by a pump (not shown) in section B. As the fluid is forced through the capillaries, heat is exchanged between the capillary walls and the working fluid. The fluid evaporates and cools the network of capillaries. The temperature at which the working fluid evaporates governs the lowest temperature that the system can achieve. The point on the heat pipe where the coldest temperature is achieved is referred to as the coldend. Next, the evaporated fluid is condensed as it exchanges heat with the condenser walls, shown as C and D. The heat pipe technology offers a wide temperature range that extends from +2000°K down to less than 77°K.

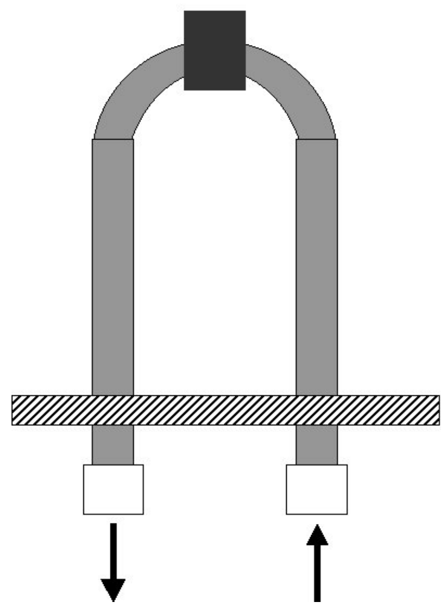

Figure 2: Schematic of the liquid nitrogen line.

The other method uses an open system in which the working fluid is forced through a pipe on which a small heat exchanger is mounted onto. By using an aluminum plate as the heat exchanger and liquid nitrogen as the working fluid, temperatures down to 77°K can be achieve. Figure 2 shows the LN2 line in thermal contact with the aluminum plate, shown as the black rectangle. On top of the heat exchanger the DUT (not shown) is mounted. Liquid nitrogen is forced through the inlet and collected in a dewar that is open to the atmosphere at the exhaust end. The flange, depicted by the cross-hashed symbol, must be designed to mate with what

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ever flange is available in the target chamber that is used to form a view port.

Ideally, the DUT should be mounted at normal incidence to the beam. The location of the beam relative to the target chamber walls may require the use of a coldfinger. The coldfinger is a device that transports thermal energy via direct contact between the DUT and the coldend. Thus the coldfinger must be designed to mate with the coldend. The coldfinger should be designed to have a high thermal diffusivity and or have a low heat capacity. Various materials meet this requirement, e.g., Al, Au, Ag, Ni, Cu an others as well some compounds and alloys. When designing a coldfinger some constraints assists in narrowing the field of material candidates. Some of the constraints are 1) easy of machining and welding, 2) weight, 3) rigid enough for load bearing, 4) ease of nuclear activation depending on radiation source, and 5) cost. The coldfingers that are described in this paper all were fabricated from 5052-SO aluminum tubing with a 5/8inch outer diameter and a wall thickness of 0.049 inches.

III. RESULTS

Figures 4, 5, 6, and 7 show the thermal characteristics of the three aluminum coldfingers that were designed and tested. Two of the three coldfingers were mounted on a Cryotiger system by IGC with PT-30 as the working fluid, which has a cooling capacity of 30 watts of thermal energy at 145°K. The 4" coldfinger was attached to a high performance nickel plated coldend, while the 19" was mounted on to a mylar wrapped coldend. The third coldfinger was the LN2 line depicted in figure 2.

Temperature was continuously monitored at three locations on the coldfinger, base, center, and tip. The base position was ½ inch from the cold end, the shaft or center position was at ½ the length of the coldfinger and tip was located at the point furthest from the cold end. During the experiment, temperature measurements were conducted every 30 seconds with the aid of a 10-channel benchtop indicator model MDSS41-TC by Omega. The temperature benchtop indicator has a temperature resolution of 0.01°C. The DUT was placed at the tip position of each coldfinger with the exception of the LN2 coldfinger, where it was position at the center position.

The analytical solution for the temperature distribution of a coldfinger as a function of position and time for the soon to be specified boundary conditions is,

$$T(x,t) = 150 + 150\frac{x}{L} + \frac{300}{\pi}\sum_{n=1}^{\infty}\frac{1}{n}\sin\left(\frac{n\pi x}{L}\right)\exp\left(-\frac{\alpha n^2\pi^2 t}{L^2}\right). \quad (1)$$

The boundary condition that lead the solution in equation (1) are as follows;

1) uniform temperature of 300°K throughout coldfinger just before t = 0.
2) At t = 0, the coldend of the coldfinger is suddenly dropped down to 150°K and held there for all t.
3) The temperature at the tip of the coldfinger (away from the coldend) is held constant at 300°K for all t.

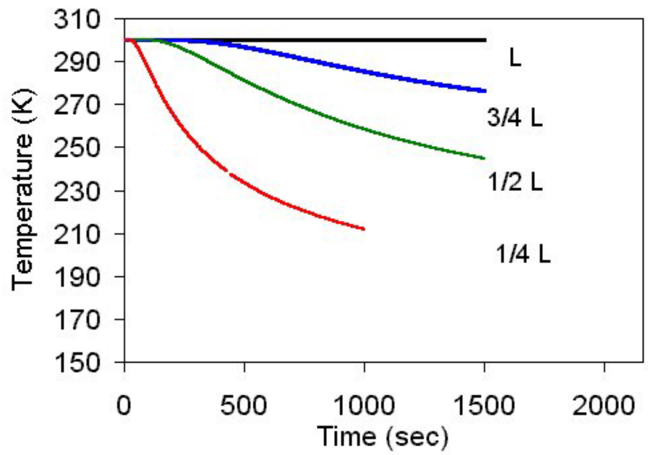
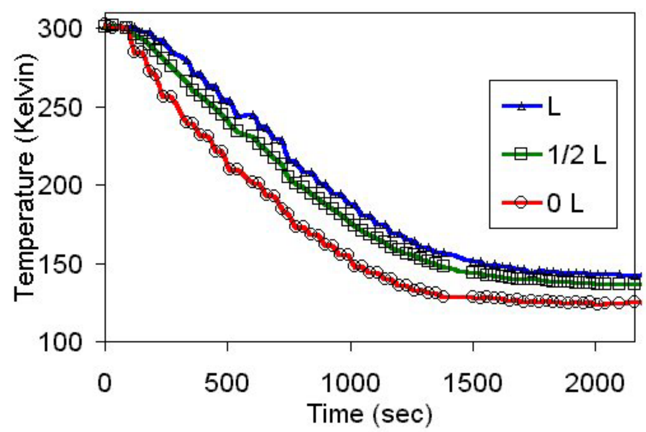


Figure 3: temperature distribution for an aluminum coldfinger of total length L = 4inches as a function of time.

Figure 3 is a plot of the temperature distribution as a function of position (x along the total coldfinger length of L) and time (t). The time constant for the 4inch coldfinger is 35.6 minutes.

Figure 4: Experimental results of a 4inch aluminum coldfinger with thermal couples placed at x = 0, x=1/2 L, and x = L, respectively.

Figure 4 shows the thermal characteristics of the 4inch



long aluminum coldfinger. The thermal constant was measured to be approximately 36minutes, as predicted by the analytical solution. The difference between figure 3 and 4 lie in that the boundary condition which lead to the analytical solution required that the x = L end be fixed in temperature, e.g., 300°K, were as in the actual experiment the point x = L was allowed to float.

Figure 5 shows the result of having a fictitious DUT (heater) that generates ~7.7watts of thermal power at x = L, were L = 4inches. The DUT was allowed to reach thermal equilibrium prior to the DUT being turned on. The time constant for cool down was ~36minutes and warm up ~40minutes.

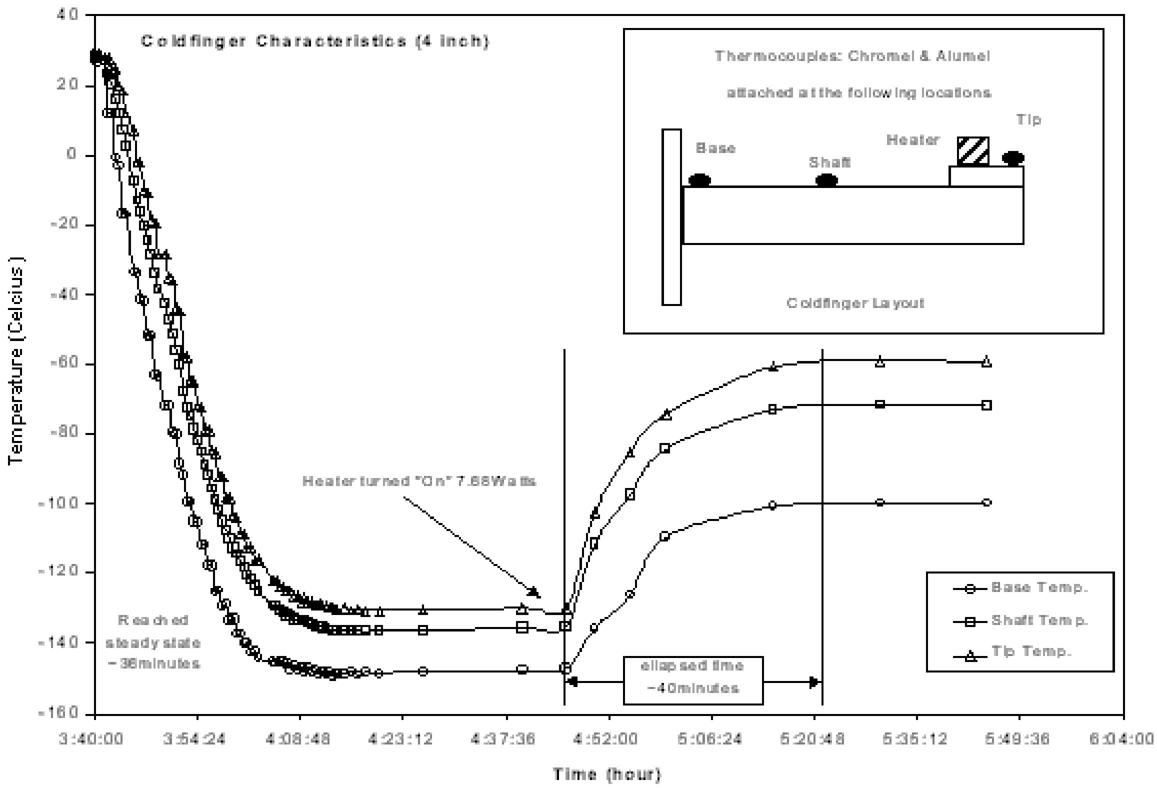


Figure 5: Thermal characteristics for the 4 inch aluminum coldfinger attached to the nickel plated high performance cold end. Inset shows the placement of the heater and chromel and alumel thermal couples along the coldfinger. The time constant of the system is ~36 – 40 minutes.

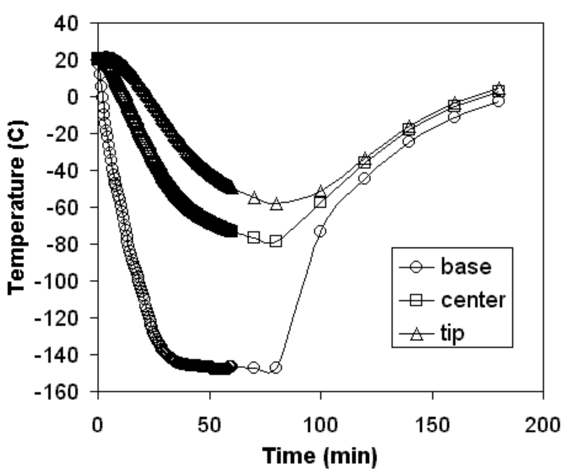


Figure 6: Thermal characteristics for the 19 inch aluminum coldfinger attached to the mylar wrapped cold end. Time constant of this system is ~38min.

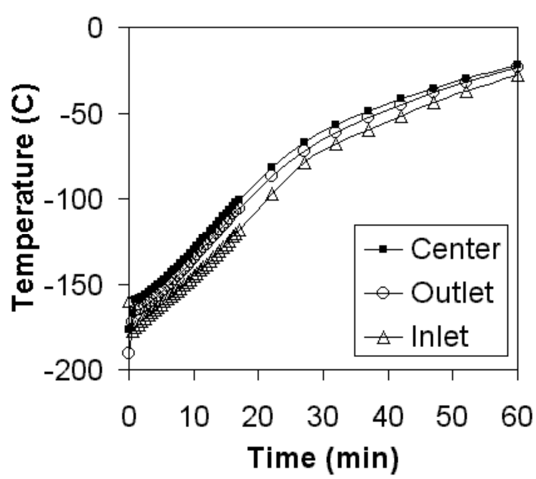


Figure 7: Thermal characteristics for the LN2 line. DUT was placed on the center position of the coldfinger.

IV. CONCLUSION

One of the main effects of temperature on semiconductors is the strong exponential dependence of the carrier concentration. This generally goes at E/k_BT, where E is the energy, k_B is Boltzmann's constant, and T is the absolute temperature. Another temperature dependent effect is the carrier mobilities and Fermi energy level. The methods presented in this paper allow researchers the ability to test the effects of temperature on single-event effects down to cryogenic temperatures, i.e., 77°K.

Picture of principal author on a good day.
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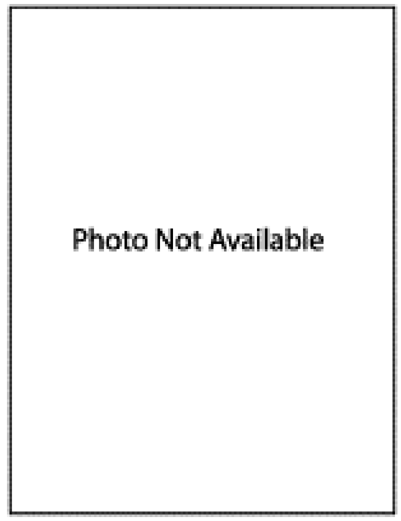
-M.S. Physics, CSLA,
-Current student in Ph.D. program UCLA



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